IMAGE GENERATION IMPLICATIONS FOR NETWORKED TACTICAL TRAINING SYSTEMS

Rick D. Bess
Visual Systems Product Manager
Loral Advanced Distributed Simulation
Bellevue, Washington

Abstract

Image Generation (IG) computers for networked simulation and training systems require additional capabilities beyond those IG's used in traditional forms of real-time simulation. This paper reviews the specific characteristics associated with the networking and tactical training nature of ground and near-ground vehicle training applications. The IG implications discussed include computational loading, scene management, advanced graphics techniques, databases, interoperability, interfaces, and required support calculations. Trends show that the future of networked simulation will continue to expand this set of special needs to support greater realism, and new types of special effects. The paper recommends an industry standard benchmark to specify, evaluate, and verify the performance of this type of image generator.

Introduction

Networked tactical training systems go beyond traditional training systems in many aspects of battlefield realism. The focus is on the tactical significance of the scene, and the overall integrity of interactions between participants. The crew members in these simulators are close to the terrain surface to see and experience the details of battlefield (Kleiss [1]). Because of the high number of simulators in large scale distributed systems, there is also a need for low cost per system.

Image generators were first used in networked tactical training from 1985 to 1990 in the DARPA research program SIMNET (Thorpe[2], Garvey [3]). This system connected armor vehicle and helicopter simulators via local and long haul networks.

Modern tactical training system programs such as the German AGPT system connects a platoon of Leopard 2 tanks together with semi-automated tank platoons. The U.S. Army Close Combat Tactical Trainer (CCTT) program will possibly connect hundreds of manned and automated vehicle simulators. Networked tactical training systems while being the exception just 7 years ago, represent an emerging standard for future training systems.

Nature Of The Simulation

This section provides a familiarization of the characteristics of networking, tactical training, related simulator components, and typical simulator configurations. Subsequent sections describe in detail their influences upon the IG.

Network Characteristics

The network represents the main conduit to influence many aspects of the IG. The network connection introduces:

1. Interaction with live simulators
2. Interaction with automated simulators
3. Interaction with simulation master control
4. Object intervisibility considerations
5. Visualization of weapon effects
6. Universal environment states
7. Increased data input/output.
8. Vehicle location/orientation to terrain
9. Moving object dead-reckoning

The key networking concept is that actions of simulators must be perceived the same way by all participants on the network. This relates to intervisibility, atmospheric and illumination conditions, and sensor simulations. For example, if only one simulator can see tracers, flares or artillery craters, then the networked tactical training benefits are lost.

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Tactical Training Characteristics

The tactical battlefield scene consists of high image complexity, and advanced atmospheric effects that contribute to the dirty battlefield as shown in the computer generated photograph in Fig. 1. Major Bill Johnson of the US Army stated "If the tactical training system can not force the crew to fight the battle with on-board sensors, then it is a failure".

Fig. 1. The dirty battlefield consists of moving models, smoke, weapon effects, and a high detail database.

The tactical training nature of this simulation influences the image generator as follows:

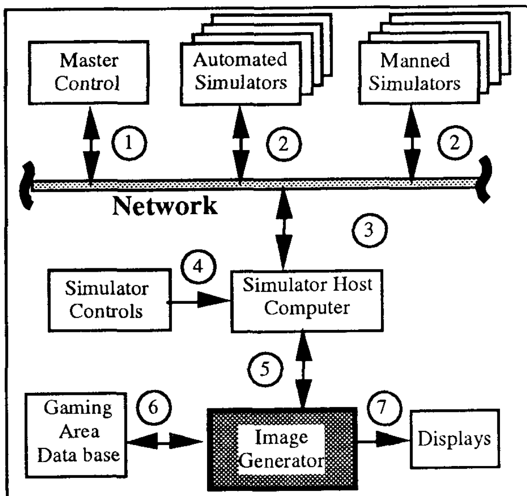
1. Preserve object intervisibility
2. Freedom of own-vehicle movement
3. Naturally constrained vehicle dynamics
4. Extended training scenarios over time
5. Full use of crew positions in vehicle
6. Full use of sensors, sights, viewports
7. Full use of all weapon systems
8. Complex gaming area content, density
9. Dynamic database changes
10. Unpredictable dynamic scene content

Three other characteristics that influence the IG are that: 1) The battlefield commander provides the instruction to the students versus a simulator instructor, 2) The students are experienced vehicle/weapon operators and are focusing on a higher degree of training versus a student in a part task trainer such as gunnery (Cannon-Bowers [4]), and 3) Students use reasonable judgement to deduce things in the scene based on the overall scenario (Krey [5]). For example, if a group of vehicles is seen in enemy territory and the student is just near enough for vehicle detection, he may conclude that they are enemy tanks due to the location and formation of the vehicles.

The key points about tactical training characteristics are that students need to see all simulators and weapon system effects in a battlefield environment that represents the real-world. There can be no simulation anomalies that compromise the tactical integrity of the game.

Simulator Components Characteristics

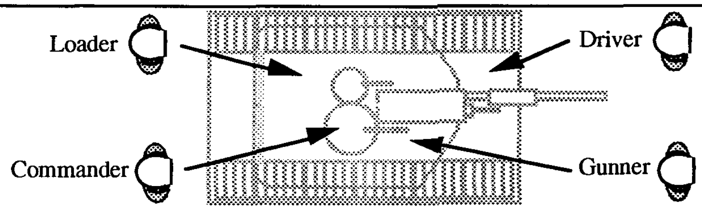
The image generator is influenced by many components of the simulator system as shown in Fig. 2.



Components That Influence Image Generator

1 Initiate dynamic changes of environmental conditions, artillary weapons, and database changes
2 Dynamic models, intervisibility, and ballistics interactions, database changes from weapon effects.
3 Receive and transmit all network information, (See 1 and 2)
4 Initiate changes in movement, weapons operation, channel configurations (e.g.sight magnification)
5 IG control (See 1 thru 4), simulation support data (e.g. ballistics, collision detection, intervisiblity, terrain feedback)
6 Database traversal (gaming area, model and texture libraries), dynamic changes (e.g. craters, bridges)
7 Heterogeneous display formats, aspect ratios, synchronized update/refresh rates, channel multiplex)

Fig. 2. Simulator component block diagram



Crew Position	Single Viewport	Juxtaposed Viewports	Magnified Sights	Sensors Displays	Popped Hatch	Laser Range
Commander	yes	yes	yes	yes	possible	possible
Gunner	yes	no	yes	yes	no	yes
Driver	no	yes	no	yes	possible	no
Loader	yes	no	no	no	no	no

Fig. 3. Full crew simulators with all weapons systems are used in tactical trainers

Channel Configuration Characteristics

Fig. 3 shows a tactical simulator diagram, which has a full crew in contrast to a part task trainer, with a partial crew. The configuration consists of a heterogeneous set of channels with side by side periscope channels, magnified sights, and sensors. Graphics throughput requirements vary greatly by channel due to parameters such as field of view, viewing range, sensors, and other factors (Bess [6]).

Image Generation Implications

This section describes the implications to the image generation portion of the simulator. Examples are based on lessons learned from development of networked tactical training systems.

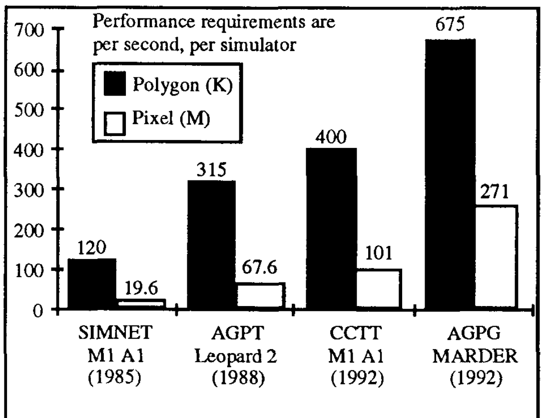


Fig. 4 Tactical simulators require more polygon throughput than traditional simulators

Compute High Complexity Scenes

Tactically relevant scenes have high amounts of terrain relief, static and dynamic models, texture, and polygons, many of which are semi-transparent. The polygon densities in the gaming area could exceed 3000 polygons / sq. km as compared to about 500 polygons / sq. km for some aviation simulators.

Fig. 4 shows simulator polygon throughput requirements as specified in Requests for Proposals for networked tactical simulator programs. Trends show that scene complexity requirements will continue to increase because customers desire real-world detail in the gaming area scene content. Added emphasis is on near field detail such as rocks, walls, grassy areas, and detail terrain relief as shown in Fig. 5.

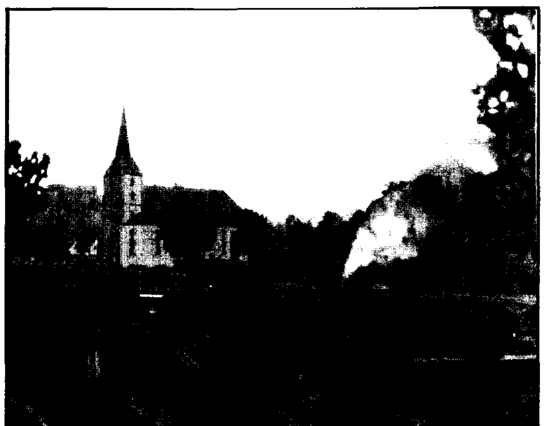


Fig. 5 Tactical simulator customers desire near field detail.

IG's require more processing from ground-based as opposed to aerial viewpoints as in Fig. 6 (Bondzeit [7]). Analysis shows that in regions of rugged terrain and many cultural features, depth complexity or pixel processing requirements increase significantly as the height of the eyepoint reduces altitude as shown in Fig 7. This phenomena is exaggerated with narrow fields of views used with magnified optical sights.

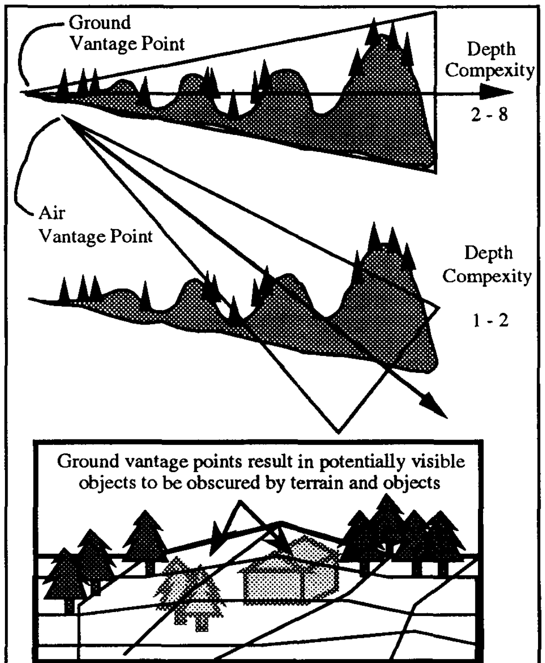


Fig. 6. Ground versus Aviation vantage point

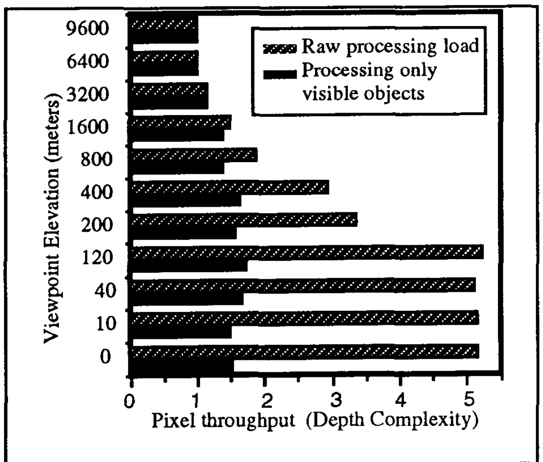


Fig. 7. Occulting is harder near the ground

Adjust to Variability of Graphics Loading

Because of the unpredictable nature of the scene content, the graphics processing requirements will vary over time among channels and within portions of a channel. Moving models, weapon effects, and non-homogeneous databases adversely affect this as shown in Fig. 8. When image complexity becomes localized, some computational resources in a rigidly pipe-lined architecture become overloaded, while others remain idle. This type of bottleneck may cause all channels of an IG to reduce frame rate because of common system timing among channels.

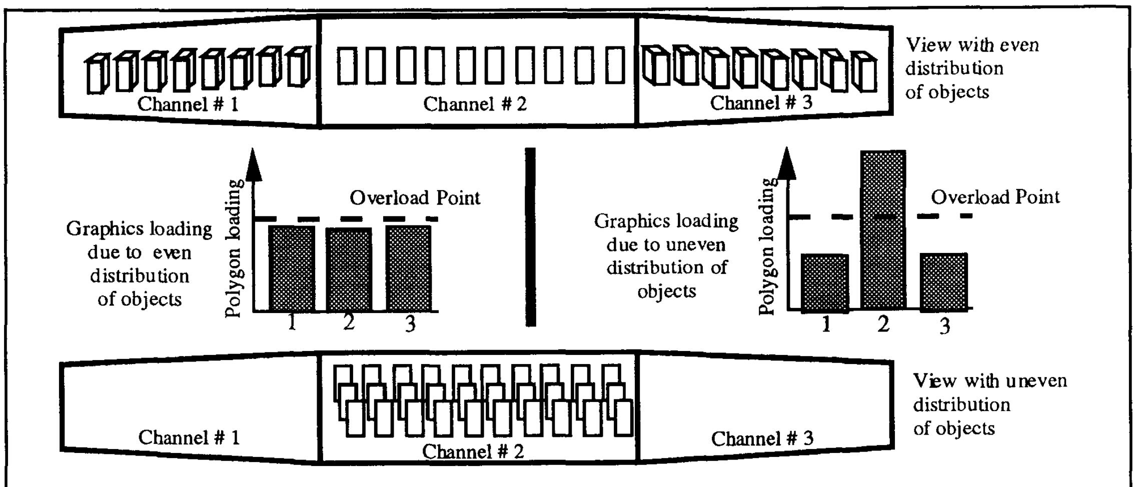


Fig. 8. Channel load variation in side by side periscope channels.

Scene Content Management

The objective of scene content management is to maximize the scene's complexity and to prevent computational overloads that would result in visual anomalies. Due to high polygon densities and graphics processing load volatility, IG's require more sophisticated scene content management approaches. Traditional scene management techniques commonly used in aviation simulators may not be appropriate due to adverse trade-offs. Two examples discussed below are extended update rate and terrain level of detail control.

Extended update rate. This feature can be disruptive because rates are frequently slow to start with, and rates must slow discretely as synchronized with refresh rate as shown in Fig. 9. For example, if the update rate is 15 Hz, any reduction is very noticeable. When tactical battles are raging, the IG may overload, but this is the time when update rate needs to be preserved.

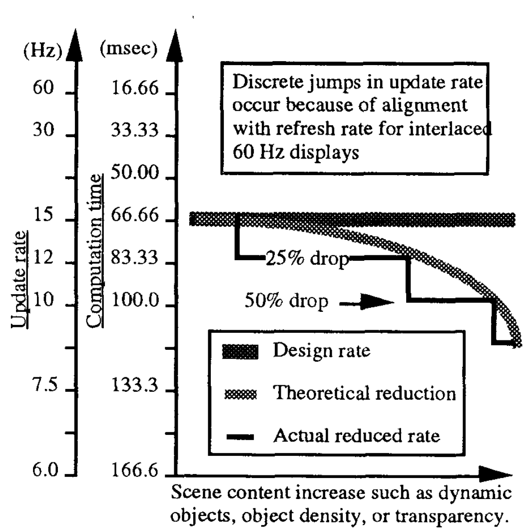


Fig. 9. Overload management that reduces update rate causes visually distracting scenes.

Terrain level of detail control. The relationship of the terrain skin to intervisibility among simulators is critical to retaining the integrity of the tactical environment. To preserve proper intervisibility among simulators, the IG must render the terrain surface at the highest level of detail within the viewing ranges for target detection. Lower detail terrain for regions beyond the target detection range could be used for features such as distant landmarks so they can be viewed in proper perspective.

Fig. 10 depicts the visual anomaly that can occur if low detail terrain is utilized within target detection ranges. Remember that other simulators broadcast their coordinates across the network based on the high level of detail terrain surface. With high detail terrain, the eyepoint can see Target B but Target A is hidden. When low detail terrain is used by the eyepoint for distant terrain regions, two anomalies occur. First, Target B is hidden under the terrain, and secondly Target A is now floating and visible to the eyepoint. This situation puts the eyepoint at risk of detection by something it can not see, and puts Target A at risk of detection when it thinks it is concealed.

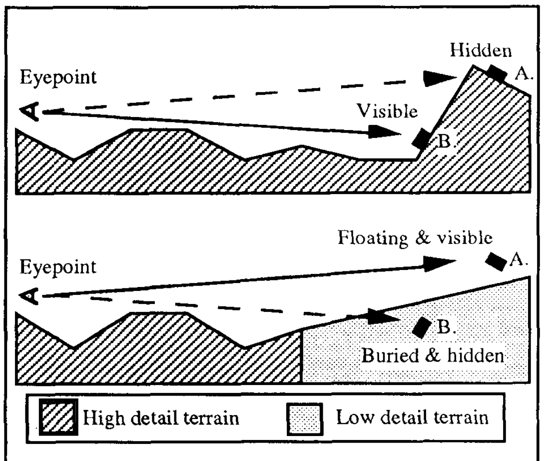


Fig. 10. Terrain surface level of detail control causes intervisibility anomalies between simulators compromising tactics.

Advanced Graphics Techniques

A key IG implication to graphics techniques involves computing correlated optical and sensor images with realistic image complexity. Also scenes must reflect the conditions of atmospheric and illumination states as controlled by the simulation master.

Atmospheric effects. Effects such as haze, fog, and smoke play a large part in tactical operations. These effects are typically under universal control from the simulation master. Conditions must be able to gradually change during the training scenario to support round the clock training. Some effects such as battlefield smoke are not homogeneous and must be simulated as a volume as shown in Fig. 11 (Bess & Soderberg [8]). Atmospheric simulation will effect intervisibility because they are visualized differently by optics and sensor systems. For example, a thermal sensor may defeat battlefield smoke where it would blind a normal magnified optical sight.

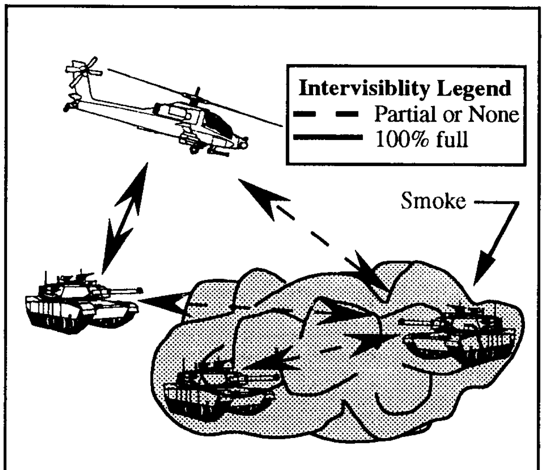


Fig. 11. Smoke simulation must support tactical uses of smoke, and preserved intervisibility characteristics on the battlefield.

Shading and scene illumination. Similar to atmospheric effects, shading and illumination must have real-time adjustment during the exercise. This is critical to simulating time-of-day and illumination with weather effects. Night simulation for light intensification sensors and local illumination from airborne flares are part of tactical simulation.

Texture processing. Texture mapping advancements are needed to add realism (Wilkerson [9]). Texture is used as a tradeoff to greater polygon density, and generally contribute to higher scene complexity. Texture capabilities that serve this purpose are photo-based and geographically-typical textures, large maps up to 512 x 512 texture pixels (texels), and high computation precision for texture blending, large quantities of texture references, large on-line texture libraries, and downloadable texture libraries.

Sensor / Optical simulation. Sensor channel imagery is computed very differently from optical imagery taking into account object surface types, atmospheric and illumination conditions (Peters [10]). Simple recoloring of optical imagery for sensor channels will limit tactical effectiveness. Thermal sensors for example must highlight hotter objects as shown in Fig 12. The hotter objects must show through vegetation to uncover camouflaged targets as in the real-world. Sensors can also defeat battlefield smoke that would blind optical viewing.

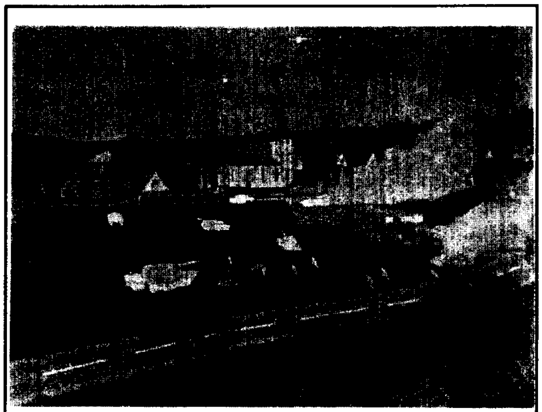


Fig. 12. Targets must be highlighted in sensor simulation for tactical training.

Simulation Support Computations

The IG frequently performs special processing computation to support simulations controlled by the simulator host computer. Special processing computations include: 1) Ballistics, 2) Terrain Feedback, 3) Model Dead Reckoning, 4) Collision Detection, and 5) Moving Model Placement.

These computations can overload just like the graphics computation portion. If the IG does not isolate support processing from the graphics pipeline, it can become stalled and visual anomalies could occur that resemble extended frame rate.

IG Interfaces

The IG Interfaces between components as described in Fig. 1. must be robust enough as to not impact the graphics pipeline, and able to expand as new features are added.

IG to simulator host. Supports ballistics, terrain feedback, intervisibility, moving model interaction, and collision detection, IG controls.

IG to databases. Supports database traversal, database downloading of gaming area assemblies, texture libraries, model libraries, higher bandwidth, and dynamic terrain change communications.

IG to displays. Supports variable update rates, channel switching, multiple configurations, pixel aspect ratios. Note that displays can be a heterogeneous mixture of monitors, projection systems, helmet mounted systems, low/high resolution, mixed update rates, unusual aspect ratios, and off-axis viewing.

Gaming Area Database

The gaming area database represents a primary source of the visual scene content. The desire for added realism in simulation requires detailed terrain, advanced database entities, correlated source data, and advanced data structures. Object detail, density, and placement is geographically typical to real-world areas in many instances. The terrain skin and feature placement can be based on real-world digital sources. Examples include Defense Mapping Agency (DMA) Digital Terrain Elevation Data (DTED) and Digital Feature Analysis Data (DFAD).

Support detail terrain. The terrain skin for tactical training must provide firing positions and limit movement as in the real-world. While course polygon grids are acceptable for low detail terrain, they don't allow sufficient detail for firing positions, river banks, and road cutouts. Terrain regions can also be multiple layers to simulate water depth in rivers.

Support advanced entities. Objects in tactical databases can have more attributes than traditional IG's. Most object surfaces are textured and many can be semi-transparent. Surfaces must also have attributes such as terrain surface hardness for vehicle dynamics simulation, and object surface material types for sensor simulation.

Databases must allow dynamic changes to the terrain skin and static objects during the exercise. For example, weapon impacts can cause craters and destroy bridges. Examples of these entities are shown in Figure 13.

Source data correlation. To ensure interoperability among simulators and among crew station channels there must be correlation among database representations (Hrabar, Joosten & Widder [11]). Real-time databases used for sensor and optical channels, ballistics, and vehicle dynamic simulations should be based on a common source. The same goes for other modules on the network such as the automated simulators, and battle observation consoles.

If the databases are not correlated, unusual errors in simulation will occur. For example, if the ballistics and visual databases are different, a tank could be concealed behind a firing position, but the bullets could pass right through the earth hitting the tank.

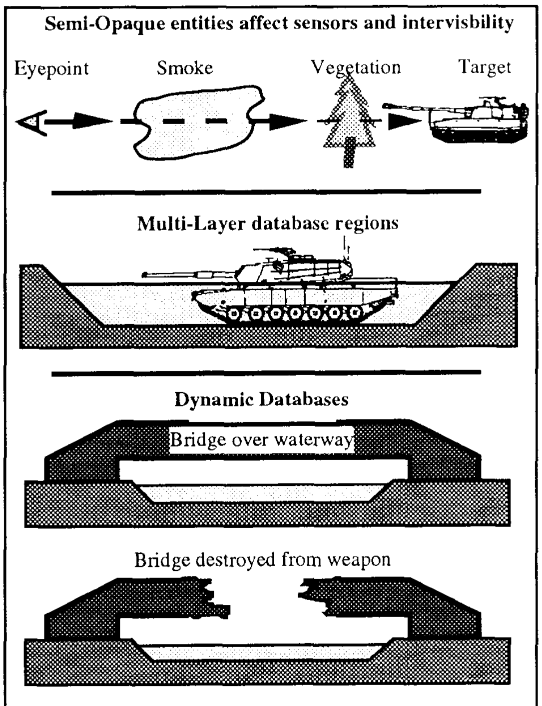


Fig. 13. Database implications

Database data structures. Tactical training databases have large varieties and quantities of models and textures. It would not be feasible to store the entire gaming area in on-line memory because of the high storage requirements. Therefore, data structures that allow real-time database traversal from hard disk to on-line memory by the IG must be provided.

Low Cost Considerations

Configurability. The ability of the IG to be efficiently configured to a specific vehicle's display needs is a key low cost consideration. The configuration should not have unused or excessive processing power or memory capacity. Therefore, the IG is desired to have sufficient granularity of processors to satisfy requirements for multi-channel, multi-crew member configurations.

Channel switching Another key element that saves cost is the ability to switch graphics resources among channels. For example, a magnified optical sight could be switched with a thermal sensor display, and could be switched with a bank of periscope viewports. A single crew member may have 6 different visual displays at his access, but can only simultaneously see 1 or 2 at a time. Via helmet mounted, head pressure, or manual switching, this feature can reduce the amount of required graphics processing by more than 2 to 1.

Preserve Intervisibility / Interoperability

The preservation of 100% intervisibility and interoperability across all crew stations, simulators, and modules is such a critical implication that it should be restated. Intervisibility is interrelated with many other aspects of the IG as previously discussed. If the IG just makes pretty pictures, the overall simulation system is not going to work. The IG must preserve intervisibility among:

1. Sensor and optical channels
2. Channels within a simulator
3. Simulators on the network.
4. Simulators and automated simulators
5. Simulators and observation modules.
6. Visual scenes and ballistics, vehicle dynamics, and collision detection simulation.

Intervisibility affects techniques for scene management, databases, and supplemental graphics techniques. It is important that the IG scenes maintain 1) constant object profiles, 2) constant high detail terrain within detection ranges, 3) high degree of placement accuracy, and 4) utilization of scene content management approaches that do not affect intervisibility. For example if an object is artificially enlarged with distance to supplement discrimination of targets (e.g. detection, recognition) in lower resolution channels, serious anomalies can occur as shown in Fig. 14.

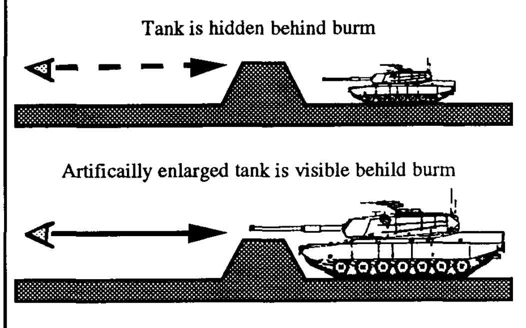


Fig. 14. Intervisibility anomaly caused by artificial target enlargement.

Need For Industry Benchmark

Image generator performance for networked tactical training applications is very difficult to specify, evaluate, and verify. It is clear that the IG must process extremely high levels of data with variable loading conditions. That is why all IG performance specifications must be fulfilled simultaneously under the conditions of this application. This section recommends that an industry standard performance benchmark and test suite be established.

The benchmark could test a candidate image generator under actual loading conditions and provide a uniform basis of comparison. This would provide a measure of quantitative and qualitative performance characteristics at sustained processing rates for known graphics techniques and precision levels.

In order to be suitable for IG specification evaluation and validation, the benchmark must replicate the processing demands typical to networked tactical trainers. This could be accomplished with a test suite that would replicate the communication from the network, and provide a standard gaming area database. Fig. 1 shows the elements that would need to be included in the test suite. This approach would provide frame by frame monitoring of the IG loading. The image generator would receive a rating based on simultaneously demonstrated performance versus performance on itemized specifications.

This is important because of the high degree of interrelationships among performance specifications. For example polygon, pixel, and moving models throughput are highly interrelated with frame update rate. Different graphics techniques such as transparency, texture, antialiasing, and shading have varies degrees of computational difficulty.

Some objectives of a test suite could be to use: 1) actual recorded network data, 2) industry standard databases and interfaces typical to application, 3) typical display channel configuration parameters, 4) a database of graduated detail, complexity, and precision, 5) animated motion paths for dynamic models, and 6) animated motion paths for "own vehicle".

Some of the major challenges to this concept are how government and industry could create such a benchmark, and how could it be unbiased toward a particular vendors IG.

Concluding Remarks

Image generation systems for networked tactical training require more realism than traditional or part-task training applications. The image generator is influenced by information flowing across the network and added battlefield realism demanded by interactive tactics. The computational processing requirements of the IG are large and fluctuate for many reasons. IG's that are unoptimized for this application are susceptible to overload conditions that reduce frame rate or cause anomalies.

The concept of an industry benchmark and test suite for IG's is recommended to provide a basis of comparison and to ensure that candidate IG's provide simultaneous graphics performance under representative loading conditions.

Acknowledgments

I would like to recognize the contributions of the Loral Advanced Distributed Simulation (LADS) vehicle simulation group, visual system development core team, application software, and database creation group members in Cambridge MA, and Bellevue WA. The network, image generation, and database technology contributions by these groups in the area of large scale distributed simulation have contributed to changing the way the industry approaches simulation and training.

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